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Research Paper
RM-228

Management of Ponderosa Pine in Even-Aged Stands in the Black Hills

Robert R. Alexander
Carleton B. Edminster

Abstract

Potential production of ponderosa pine in the Black Hills is simulated for various combinations of stand density, site index, age, and thinning schedule. Such estimates are needed to project future development of stands managed in different ways for various uses.

Cover Photo.—Second-growth Black Hills ponderosa pine on an average site thinned to GSL 60. Stand now averages 6.7 inches d.b.h., was first thinned in 1963, and was rethinned in 1973.

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Robert R. Alexander, Chief Silviculturist
and
Carleton B. Edminster, Mensurationist
Rocky Mountain Forest and Range Experiment Station[1]

[1]*Headquarters is in Fort Collins, in cooperation with Colorado State University.*

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Silviculture of Black Hills Ponderosa Pine

Black Hills ponderosa pine (*Pinus ponderosa* Laws) cover type occupies about 1 million acres in the Black Hills of South Dakota and Wyoming, and associated Bear Lodge Mountains of Wyoming. These forests form a unique, isolated segment of the interior ponderosa pine type. Ponderosa pine is the principal timber species, and usually occurs in pure stands (Alexander 1974, Boldt and Van Deusen 1974). The main timber-producing areas are the crystalline core area, which is characterized by rough to rounded hills and divides generally ranging from 4,300 to 6,000 feet elevation, and the limestone plateau. In the east, the plateau forms a narrow ridge that occasionally flattens out to narrow uplands with elevations of 3,600 to 4,400 feet; in the west, it forms wide, rather level divides separated by narrow, steep valleys that range in elevation from 4,500 to 7,000 feet.

Ponderosa pine forests in the Black Hills have provided a variety of wood products since they were first cut beginning in the mid-1870's. During the past century, virtually all of the area's unreserved and operable forest acres have been cut over once; and many acres have received multiple partial cuts. Large tracts which were logged free of regulatory restraints—before establishment of the Forest Reserve in 1897—were commercially clearcut and literally stripped of all trees large enough to produce a railroad tie or mine timber (Boldt and Van Deusen 1974).

The long history of cutting, together with losses caused by insects, diseases, winds, and fires, has nearly eliminated the original old-growth sawtimber stands on about one-half of the commercial forest area. Only light stands of scattered, old-growth remnants are left on the remaining acres (Boldt and Van Deusen 1974). Despite all of the harvesting and losses to destructive agents, growing stock has not been seriously depleted.

Black Hills ponderosa pine forests have produced large quantities and varied kinds of wood products. They have also provided forage for livestock and big game, habitats for a variety of other wildlife, water for domestic, industrial and agricultural uses, and recreational opportunities for millions of people. Today, all of these demands on the forest are increasing, and how the Black Hills ponderosa pine forests are managed will affect all resources and uses. For example, if timber production is the primary objective, growing stock levels (GSL)[2] should be high, but forage production and water yields can be substantially increased only at low GSL's. Carefully planned harvests that maintain low to medium growing stock levels are generally considered appropriate to improve developed recreational opportunities and enhance foreground esthetics. Improvement of middleground and background esthetics generally require open forests, and both low and high growing stock levels to provide contrasts. Wildlife habitat requirements vary from uncut to open forests.

Although land-use planners and land managers must increasingly direct their efforts toward multiple uses, these practices must be based on sound silvicultural principles of the forest type involved. They must understand the tradeoffs between the timber resource and other physical, social, and economic considerations.

Black Hills ponderosa pine has been managed longer and more intensively than any other Rocky Mountain timber type. Regeneration silviculture has been learned by experience during a century of harvesting that has included all even- and uneven-aged cutting methods, and has led to the conversion of old-growth stands to well-stocked, manageable stands of second-growth, with little or no reduction in productivity. Management of Black Hills ponderosa pine is somewhat simplified because these forests reproduce readily and prolifically, and are free of dwarf mistletoe.

Today, managers are not only concerned with prompt restocking of cutover areas with new reproduction, but also (1) increasing the growth rate of the new stand by control of stand density, and (2) improving quantity and quality of yields by periodic thinning to maintain stocking control and growth rates, and to reduce mortality. Under intensive management, annual net increment for Black Hills ponderosa pine can be expected to be from 100 to 300 fbm per acre, depending

[2]Growing stock level (GSL) is defined as the residual square feet of basal area per acre when average stand diameter is 10 inches or more. Basal area retained in a stand with an average diameter of less than 10 inches is less than the designated level (Myers 1971, Edminster 1978). Tables A-1, A-2, and A-3 give the number of trees, basal area, and square spacing for stands with average diameters after thinning of 2 to 10 inches, for GSL's 40 to 160.

upon growing stock level, site index, rotation age, and cutting cycle (Edminster 1978).

Control of stand density offers the greatest opportunity for increasing wood production by increasing growth and reducing mortality, but harvested stands must be replaced promptly to reduce the time required to reach maximum yields. However, stumpage values will have to improve in the Black Hills before the manager can do the cultural work required to increase timber production.

Establishment of Regeneration

Black Hills ponderosa pine is most easily maintained as a vigorous, productive forest under even-aged management. Shelterwood is the best cutting method for most ponderosa pine condition classes (Boldt 1973, Boldt and Van Deusen 1974). It takes advantage of the species' natural habit of forming even-aged stands and provides continuous overstory protection of the site, which retards development of competing understory vegetation, while providing a well-distributed source of seed. A uniform, two-cut shelterwood is preferred, but a three-cut shelterwood can be used in very heavily stocked, mature stands where risk of logging residue buildup, windfall risk, and logging damage to established regeneration are likely to be high. Seed-tree and clearcutting methods have been used in the Black Hills, but both risk loss of seed source, provide little control of competitive understory vegetation, and generate large amounts of logging residue. Uneven-aged management is generally inappropriate for regeneration, but uneven-aged management cutting methods may be appropriate for multiple use (Alexander 1974, Boldt and Van Deusen 1974). They are not discussed in this paper, because suitable growth and yield prediction tools are not available for managed, uneven-aged, Black Hills ponderosa pine stands.

Ponderosa pine usually regenerates readily and abundantly under even-aged management, within a short time after the seed or final cut. There is some variation among habitat types, however. Ordinarily, only the absence or loss of seed source results in poorly stocked or non-stocked areas that must be regenerated artificially. Boldt and Van Deusen (1974) summarized guidelines for planting and direct seeding. If areas are not adequately stocked within 5 years after final harvest, the manager must take action under the regulations of the National Forest Management Act of 1976 to artificially restock the areas.

Boldt and Van Deusen (1974) recommend planting 500 to 800 trees per acre. The minimum number suggested should provide sufficient number of stems when the average diameter of the stand reaches 5 inches d.b.h. for GSL's up to 80. However, if Black Hills ponderosa pine is to be managed at higher GSL's, a minimum 800 trees per acre should be planted, and 1,000 to 1,200 trees per acre would provide the manager with a better choice of crop trees when the stand average diameter reaches 5 inches d.b.h.

Need for Early Precommercial Thinning

Establishing a new stand is only the beginning. Trees must have room to grow to reach merchantable size. In the Black Hills, extremely high densities are common in naturally regenerated stands. Dense seedling stands often contain more than one tree per square foot. Because natural thinning normally proceeds very slowly, an initially crowded stand may remain overstocked for its entire life (Boldt and Van Deusen 1974). For example, on one plot in the Black Hills, stand density was 15,000 stems per acre at age 12 years. At age 63 years, it still contained 6,600 trees per acre, with an average stand diameter of only 2.4 inches d.b.h. (Myers and Van Deusen 1960). More than one-half of a 120-year rotation has passed without any usable wood production. For acceptable growth rates under these dense conditions, precommercial thinning is needed to reduce stand density to 800 to 1,200 stems per acre during the first 10 years of the life of the stand.

When enough seedlings become established within 5 years after the seed-cut of a shelterwood method, the removal cut should be made promptly to avoid suppression of the new stand. Care must be exercised to avoid excessive damage to the established reproduction, otherwise the new stand may not adequately restock.

Estimates of Growth Under Intensive Management

Intensive management of Black Hills ponderosa pine forests provides many opportunities for increasing usable wood production, but estimates of future stand development under various management regimes are needed.

Information available on the growth of ponderosa pine from sapling stage to final harvest, under even-aged management, with a shelterwood cut, is provided by field and computer simulation procedures developed by Myers (1971) and refined by Edminster (1978). The procedures were developed from field data on past growth related to stand density, age, and site quality. Data were obtained from a large number of both permanent and temporary plots established in thinned and natural stands throughout the Black Hills.

The modeling concept used in these programs holds that the whole stand is the primary model unit, as characterized by average values. The equations upon which the growth and yield simulations are based are given in Myers (1971). The programs project stand development by consecutive, 10-year projection periods, with relationships to project average stand diameter, average dominant and codominant height, and number of trees per acre. Average diameter at the end of a projection period is a function of average diameter at the beginning of the period, site index, and basal area per acre. Periodic average dominant and codominant height growth at managed stand densities is a function of age and site index. Periodic mortality is a function of average diameter and basal area per acre. Stand volume equations are used to compute total cubic feet per acre; factors are computed to convert this to merchantable cubic feet and board feet. Prediction equations are included to estimate the effects of differing intensities of thinning from below on average diameter, average dominant and codominant height, and trees retained per acre.

Yield simulations discussed in the following paragraphs were made to the same hypothetical initial stand conditions for all growth parameters:

1. Average age at first GSL thinning is 30 years.
2. Average stand diameter is 4.5 inches d.b.h.[3]
3. Stand density is 1,000 trees per acre.
4. Site index is 50-, 60-, 70-, and 80-foot classes, at base age 100 years (Meyer 1961)
5. Projections were made for 50 years (stand age 80 years) and 90 years (stand age 120 years)
6. Thinnings from below were made every 20 and 30 years to growing stock levels (GSL) of 40, 60, 80, 100, 120, 140, and 160, with initial and subsequent entries made to the same growing stock level
7. A two-cut shelterwood option was used. The seed cut was made 20 years before the final cut and retained 50% of the subsequent GSL.
8. Minimum size for inclusion in board foot volume determination was 10 inches d.b.h. to an 8-inch top. Volumes were determined from tables prepared by Myers (1964).[4]
9. All entries were made as scheduled even though all thinnings could be precommercial.

Diameter Growth

Periodic mean annual diameter growth of Black Hills ponderosa pine is related to stand density and site quality, but is affected little by the cutting cycles tested. Cutting cycles do influence average stand diameter, however, because thinning from below increases average diameter at each entry. Actual basal area in a stand with an average diameter of less than 10 inches d.b.h. continues to increase, because periodic thinning does not reduce basal area to a fixed (GSL) amount until an average stand diameter of 10 inches d.b.h. is reached. Consequently, the rate of diameter growth for a given GSL is not constant over time, and is essentially a negative exponential function of basal area per acre in the program. In contrast, periodic diameter growth is a linear function of site index, so that differences in diameter growth resulting from site quality are constant throughout the range of GSL's and rotations examined.

Growth rates and changes in diameter resulting from thinning frequency were examined to determine average size of trees relative to rotation age. With a 20-year cutting cycle, for example, trees reach average stand diameters of 10.2 to 18.3 inches d.b.h. after 80 years, and 12.6 to 26.9 inches d.b.h. after 120 years for the range of GSL's and site indexes tested (table 1). On an average site (index 70), with a 20-year cutting cycle, mean stand diameters reached 10 inches d.b.h. at about 50 to 90 years of age for the range of GSL's 40 to 160 (fig. 1).

Height Growth

Periodic mean annual height growth of ponderosa pine increases with site index and decreases with age, but is unaffected by GSL's, cutting methods, or the cutting cycles examined. However, since fewer and, therefore, taller trees are left after each thinning from below, the mean height of the dominant and codominant trees is increased slightly at each entry. The increase is positively correlated with thinning frequency and negatively correlated with GSL.

Basal Area Growth

Periodic mean annual basal area increment is related to growing stock level, site quality, frequency of thinning, and rotation age. Because actual basal area continues to increase in a stand until average stand diameter reaches 10 inches d.b.h. and thinning reduces basal area to a fixed amount (GSL), the rate of basal area growth for a given GSL is not constant over time. Periodic basal area increment increases as growing stock level increases from 40 to 140, but the rate of increase diminishes as stand density increases. At GSL's above 140, basal area increment declines on all sites. Periodic mean basal area growth also increases as site index increases. Moreover, the differences in basal area growth between site classes become progressively greater as GSL increases. Periodic mean basal area increment is greater with a 30-year cutting cycle than with a 20-year entry at all rotations examined, for GSL's 40 to 140.

Total Cubic-Foot Volume Increment

Cubic-foot volume production is related to stand density, site quality, rotation age, and frequency of thinning (table 2). Although mean annual cubic volume increment increases as growing stock level and site index increases, the rate of increase diminishes as GSL increases, while the differences in growth between site classes becomes greater (fig. 2) (table 3). Cubic volume increment for both rotations examined will apparently continue to increase at GSL's above 160 on site index 70 and 80 lands, but level off or decline on site index 50 and 60 lands at GSL's greater than 160. Mean annual cubic volume increment is generally greater with a 120-year rotation and a 30-year cutting cycle for all GSL's and site indexes examined.

[3]*Average diameter is the diameter of the tree of average basal area; it is not the average of all the tree diameters.*

[4]*Utilization standards in the Black Hills for board-foot volume determination are changing to 8 inches d.b.h. to a 6-inch top. Estimates of board-foot volume growth and production in this paper may be slightly lower than actual board foot volumes because of the change in utilization standards.*

Table 1.—Estimated average diameter (inches) and number of trees per acre of Black Hills ponderosa pine at final harvest in relation to growing stock level, rotation age, cutting cycle, and site index

		Growing stock level													
		40		60		80		100		120		140		160	
Rotation age	Cutting cycle	No. of trees	Diameter	No. of trees	Diameter	No. of trees	Diameter	No. of trees	Diameter	No. of trees	Diameter	No. of trees	Diameter	No. of trees	Diameter
								Site Index 50							
80	20	22	16.5	39	14.8	64	13.3	92	12.3	119	11.5	153	10.8	189	10.2
120		9	23.7	18	20.6	29	18.5	46	16.4	63	15.3	89	13.9	123	12.6
80	30	24	15.9	45	14.1	72	12.7	101	11.7	131	11.0	165	10.4	202	9.8
120		10	22.9	20	19.6	33	17.6	50	15.9	67	14.9	94	13.6	128	12.4
								Site Index 60							
80	20	21	17.0	38	15.3	60	13.9	83	13.0	111	12.1	145	11.3	180	10.7
120		9	24.4	17	21.5	27	19.4	40	17.6	56	16.3	77	15.0	105	13.7
80	30	23	16.4	42	14.6	67	13.2	92	12.4	124	11.5	155	10.9	192	10.3
120		10	23.5	18	20.7	30	18.5	45	16.7	62	15.6	82	14.6	109	13.5
								Site Index 70							
80	20	20	17.5	36	15.8	55	14.5	80	13.3	106	12.6	132	12.0	168	11.2
120		8	25.4	15	22.5	25	20.2	37	18.5	52	17.1	66	16.2	90	14.9
80	30	21	17.1	39	15.2	63	13.8	90	12.7	120	11.9	147	11.4	183	10.9
120		9	24.8	17	21.7	28	19.2	41	17.6	56	16.5	74	15.5	99	14.3
								Site Index 80							
80	20	18	18.3	34	16.4	53	15.0	77	13.7	100	13.1	130	12.3	154	11.9
120		7	26.9	14	23.5	22	21.4	34	19.4	46	18.2	62	16.9	79	15.9
80	30	20	17.7	37	15.8	61	14.1	85	13.2	110	12.6	142	11.8	174	11.2
120		8	25.8	15	22.7	25	20.4	38	18.5	50	17.5	68	16.2	87	15.3

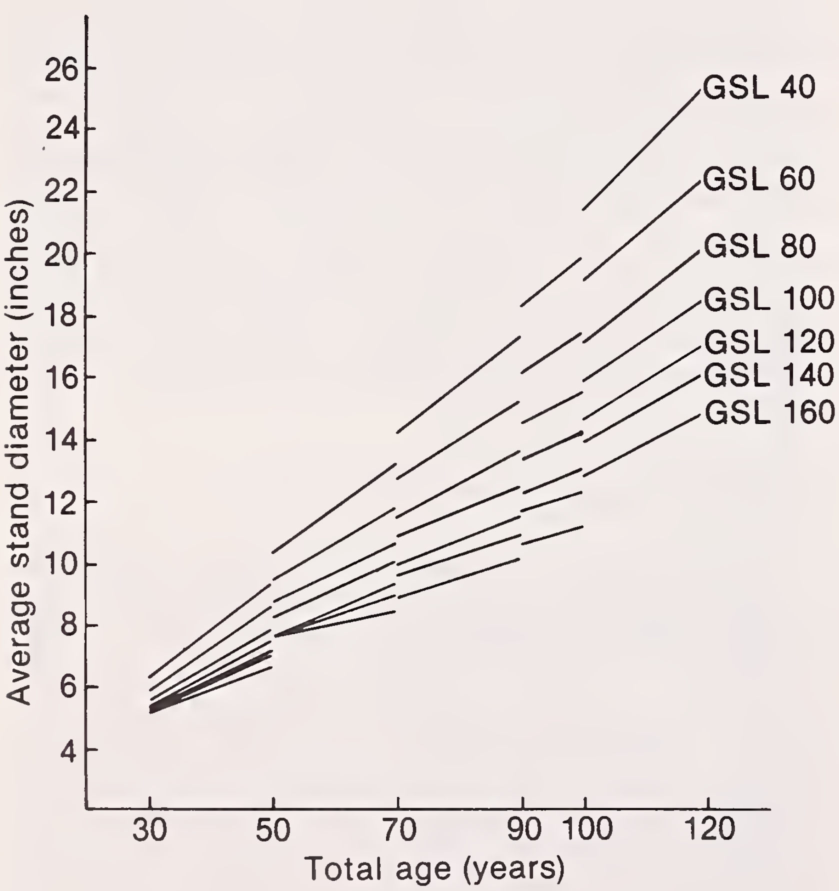

Figure 1.—Estimated average stand diameter of Black Hills ponderosa pine in relation to age and GSL on site index 70 lands, with a 20-year thinning interval.

Table 2.—Estimated total cubic-foot volume production per acre, of Black Hills ponderosa pine in relation to growing stock level, rotation age, cutting cycle, and site index

Rotation age	Cutting cycle	Growing stock level 40	60	80	100	120	140	160
years		*thousand cubic feet*						
				Site Index 50				
80	20	1.91	2.24	2.55	2.80	2.96	3.04	3.12
120		2.95	3.67	4.20	4.56	4.82	4.94	5.04
80	30	2.04	2.37	2.63	2.80	2.96	3.10	3.19
120		3.10	3.80	4.33	4.66	4.91	5.02	5.10
				Site Index 60				
80	20	2.39	2.90	3.32	3.61	3.83	3.97	4.06
120		3.71	4.62	5.30	5.88	6.24	6.48	6.67
80	30	2.56	3.02	3.38	3.66	3.90	4.12	4.20
120		3.90	4.81	5.56	6.12	6.50	6.82	6.98
				Site Index 70				
80	20	2.94	3.50	4.02	4.44	4.78	5.01	5.13
120		4.48	5.62	6.48	7.19	7.75	8.22	8.46
80	30	3.12	3.72	4.19	4.55	4.81	5.06	5.20
120		4.73	5.90	6.84	7.56	8.16	8.53	8.84
				Site Index 80				
80	20	3.50	4.29	4.88	5.32	5.68	5.96	6.16
120		5.26	6.70	7.85	8.78	9.54	9.97	10.26
80	30	3.76	4.42	5.01	5.49	5.82	6.03	6.20
120		5.63	7.04	8.18	9.12	9.86	10.43	10.70

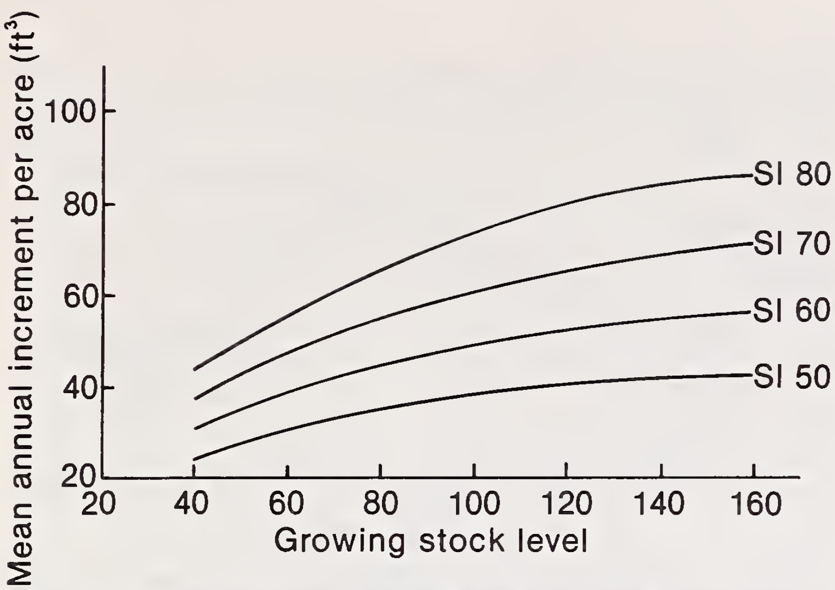

Figure 2.—Estimated mean annual total cubic-foot volume increment per acre of Black Hills ponderosa pine in relation to growing stock level for a 120-year rotation with a 20-year thinning interval.

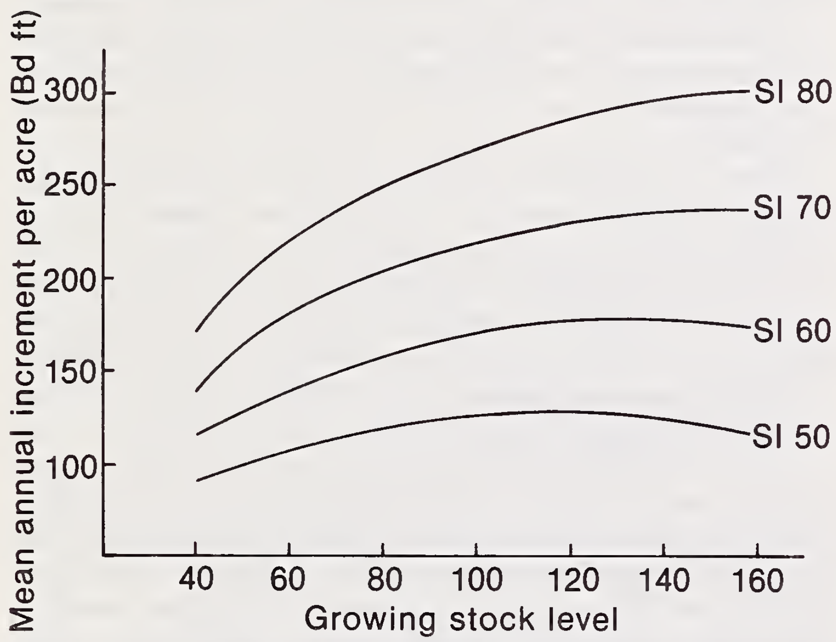

Figure 3.—Estimated mean annual board-foot volume increment per acre of Black Hills ponderosa pine in relation to growing stock level for a 120-year rotation with a 20-year thinning interval.

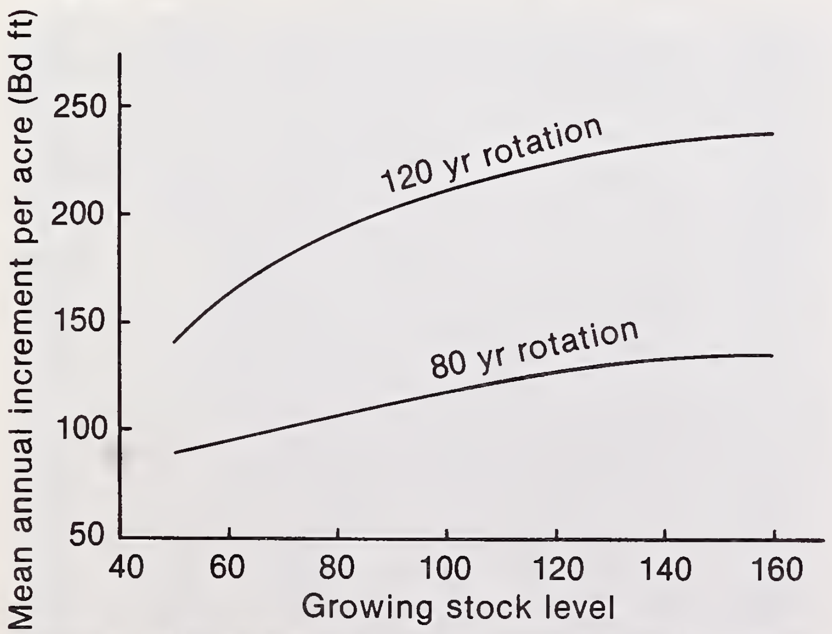

Figure 4.—Estimated mean annual board-foot volume increment per acre of Black Hills ponderosa pine on site index 70 lands with a 20-year thinning interval in relation to GSL and rotation age.

Table 3.—Estimated mean annual total cubic-foot volume increment per acre of Black Hills ponderosa pine in relation to growing stock level, rotation age, cutting cycle, and site index

Rotation age	Cutting cycle	Growing stock level 40	60	80	100	120	140	160
years		*cubic feet*						
		Site Index 50						
80	20	23.9	28.0	31.9	35.0	37.0	38.0	39.0
120		24.6	30.6	35.0	38.0	40.2	41.2	42.0
80	30	25.5	29.6	32.9	35.0	37.0	38.8	39.9
120		25.8	31.7	36.1	38.8	40.9	41.8	42.5
		Site Index 60						
80	20	29.9	36.2	41.5	45.1	47.9	49.6	50.9
120		30.9	38.5	44.2	49.0	52.0	54.0	55.6
80	30	32.0	37.8	42.2	45.8	48.8	51.3	52.5
120		32.5	40.1	46.3	51.0	54.2	56.8	58.2
		Site Index 70						
80	20	36.8	43.8	50.2	55.5	59.8	62.6	64.1
120		37.3	46.8	54.0	59.9	64.6	68.5	70.5
80	30	39.0	46.5	52.4	56.9	60.1	63.2	65.0
120		39.4	49.2	57.0	63.0	68.0	71.1	73.7
		Site Index 80						
80	20	43.8	53.6	61.0	66.5	71.0	74.5	77.0
120		43.8	55.8	65.4	73.2	79.5	83.1	85.5
80	30	47.0	55.3	62.6	68.6	72.8	75.4	77.5
120		46.9	58.7	68.2	76.0	82.2	86.9	89.2

Table 4.—Estimated total board-foot volume production per acre of Black Hills ponderosa pine in relation to growing stock level, rotation age, cutting cycle, and site index (trees 10 inches d.b.h. and larger to an 8-inch top)

Rotation age	Cutting cycle	Growing stock level 40	60	80	100	120	140	160
years		*thousand board feet*						
		Site Index 50						
80	20	4.40	4.88	5.28	5.52	5.60	5.36	4.96
120		11.04	12.96	14.28	15.12	15.36	14.88	13.80
80	30	4.32	4.88	5.04	5.20	5.04	4.72	4.16
120		11.04	13.20	14.28	14.88	15.00	14.04	12.60
		Site Index 60						
80	20	5.68	6.40	7.12	7.68	7.84	7.84	7.52
120		13.92	16.80	18.84	20.16	21.24	21.36	20.64
80	30	5.92	6.40	6.72	6.96	7.04	6.96	6.72
120		14.28	16.92	18.84	20.16	20.88	20.64	19.92
		Site Index 70						
80	20	7.20	8.08	8.96	9.76	10.40	10.64	10.64
120		16.80	21.48	24.36	26.16	27.60	28.08	28.20
80	30	7.68	8.48	8.96	9.28	9.60	9.76	9.76
120		18.12	21.84	24.60	26.76	27.84	28.20	28.32
		Site Index 80						
80	20	8.88	10.24	11.36	12.32	13.20	13.76	14.08
120		20.64	26.04	29.64	32.16	34.20	35.64	35.88
80	30	9.76	10.88	11.60	12.16	12.64	12.80	12.96
120		22.32	26.64	29.88	32.52	34.32	35.64	36.00

Board-Foot Volume Increment

Board-foot volume production is related to all stand parameters evaluated (table 4). Mean annual sawtimber volume growth increases on site index 70 and 80 lands as stand density increases from GSL 40 to 140. Above GSL 140, growth begins to level off. On site index 50 and 60 lands, growth generally levels off or declines at GSL's above 120 (fig. 3) (table 5).

Board-foot volume growth increases with site quality, and the differences in growth between site classes become greater as GSL increases. Throughout the range of GSL's tested, average annual board-foot increment per acre is always greater for all site classes on a 120-year rotation (fig. 4). There are no practical differences in board-foot volume growth between 20- and 30-year cutting cycles for the range of site indexes and GSL's tested (fig. 5) (table 5).

Maximizing Board-Foot Volume Yields

What yields can be expected with intensive management of Black Hills ponderosa pine to maximize timber production? If the objective is to integrate timber production with other resources uses, what are the timber tradeoffs? How can these objectives be attained with the fewest precommercial thinnings?

The largest volume production per acre (about 36,000 fbm) is attained on site index 80 lands, at GSL's

Table 5.—Estimated mean annual board-foot volume increment per acre of Black Hills ponderosa pine in relation to growing stock level, rotation age, cutting cycle, and site index (trees 10 inches d.b.h. and larger to an 8-inch top)

Rotation age	Cutting cycle	Growing stock level 40	60	80	100	120	140	160
years		board feet						
				Site Index 50				
80	20	55	61	66	69	70	67	62
120		92	108	119	126	128	124	115
80	30	54	61	63	65	63	59	52
120		92	110	119	124	125	117	105
				Site Index 60				
80	20	71	80	89	96	98	98	94
120		116	140	157	168	177	178	172
80	30	74	80	84	87	88	87	84
120		119	141	157	168	174	172	166
				Site Index 70				
80	20	90	101	112	122	130	133	133
120		140	179	203	218	230	234	235
80	30	96	106	112	116	120	122	122
120		151	182	205	223	232	235	236
				Site Index 80				
80	20	111	128	142	154	165	172	176
120		172	217	247	268	285	297	299
80	30	122	136	145	152	158	160	162
120		186	222	249	270	286	297	300

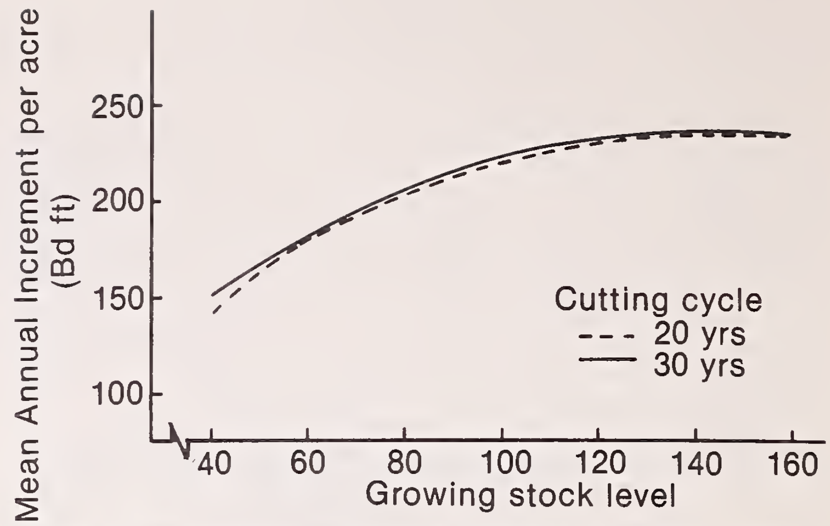

Figure 5.—Estimated mean annual board-foot volume increment per acre of Black Hills ponderosa pine on site index 70 lands in relation to GSL and thinning interval.

140 to 160, on a 120-year rotation, with either a 20- or a 30-year cutting cycle (table 4). These stands will contain between 60 and 90 trees per acre, with an average diameter of between 15 and 17 inches d.b.h. at rotation age (table 1).

Maximum volume production on site index 70 lands is also at GSL's 140 to 160. Volume production declines substantially when GSL is reduced below 140 on site index 70 and 80 lands. The decline is greater with each successive reduction in GSL. On site index 50 and 60 lands, the largest volume production occurs at GSL's 120 to 140 on a 120-year rotation with a 20-year cutting cycle (table 4) (fig. 6).

Table 4 also shows the amount of volume given up as GSL is reduced from the level of maximum production to 40 for all combinations of stand parameters examined. Moreover, it shows that more volume can be produced over the same time span with a 120-year rotation than with an 80-year rotation. For example, on site index 80 lands, at GSL's 140 to 160, average volume production per acre on two 120-year rotations or 240

Figure 6.—Second-growth Black Hills ponderosa pine on an average site thinned to GSL 120. Stand now averages 6.2 inches d.b.h., was first thinned in 1963, and was rethinned in 1973.

years would be about 72,000 fbm, compared with about 40,000 fbm per acre on three 80-year rotations, also 240 years.

Whether the board-foot volume production potentials can be achieved depends largely on how much money can be invested in thinning. We have assumed that once a stand reaches a minimum size of 5 inches average d.b.h., intermediate thinnings will be made as scheduled. If economic constraints limit managers to only one precommercial thinning in the life of the stand, their options are severely restricted. For example, on site index 50 lands, stand density must be reduced to GSL's 60 and the cutting cycle increased to 30 years (table 6). On site index 60 and 70 lands, a GSL of 100 can be maintained with a 30-year cutting cycle, and on site index 80 lands a GSL of 120 can be maintained.

Thinnings to a constant GSL have been assumed up to now. However, if only one precommerical thinning is possible, managers can increase their flexibility by changing GSL's with successive reentries. For example, on site index 70 lands, with a 30-year cutting cycle, stand density is initially reduced to GSL 100. At the time of the second thinning, GSL is increased to 120, and increased to GSL 140 with the third thinning. Volume production will be less than maximum, but reasonably close to the volume available from a stand maintained at a constant GSL 140. Attempts to raise the GSL to 140 at the time of the second entry into the stand would result in a second precommercial thinning. By following this procedure, managers can increase GSL on site index 50 lands from 60 to 100.

The manager has another option if only one precommercial thinning is possible. The initial thinning can be made on schedule and the second entry delayed until the stand reaches minimum merchantable size. This will increase the thinning interval to 40 years or more, increase the length of rotation, and result in less than maximum volume production.

Where economic conditions permit investment of funds in two precommercial thinnings, the manager has the opportunity to maximize timber production at a constant GSL 100 on site index 50 lands to GSL 140 on site index 80 lands with a 30-year thinning interval (table 6).

Managers also may elect to change GSL's with successive reentries regardless of the number of precommercial thinnings that are economically possible. With this procedure, the concern about retaining large numbers of trees early in the life of the stand and small numbers of trees later in the rotation can be avoided. For example, stand density can be initially reduced to GSL's 60 to 80 and successively increased to GSL's 100 to 140, depending upon site quality and cutting cycle. Volume production would be less than if density were maintained at a constant and higher initial GSL, however.

Tradeoffs to Increase the Values of Other Resources

Understory vegetation on Black Hills ponderosa pine forested ranges is the potential food supply for many

Table 6.—Number of precommercial thinnings of Black Hills ponderosa pine in relation to growing stock level cutting cycle and site index

Cutting cycle	Site index	Growing stock level						
		40	60	80	100	120	140	160
– years –								
20	50	2	2	2	2	3	3	4
	60	2	2	2	2	3	3	3
	70	1	2	2	2	2	3	3
	80	1	2	2	2	2	3	3
30	50	1	1	2	2	2	3	3
	60	1	1	1	1	2	2	3
	70	1	1	1	1	2	2	2
	80	1	1	1	1	1	2	2

big game animals and livestock. Available forage is strongly influenced by timber overstory, however. Understory production is inversely related to overstory density (Pase 1958, Krantz and Linder 1973). Using the following regression model developed by Pase (1958):

$$\text{Log } y = 3.22260 - 0.00936x$$

where y = herbage production (pounds per acre)
x = basal area (square feet per acre)
Log = logarithm to base 10

forage production is estimated to vary from about 1,700 pounds per acre on clearcut areas to as little as 20 pounds per acre under dense stands (200 or more square feet basal area per acre) (fig. 7). With 80 square feet basal area, a common density for managed stands in the Black Hills, forage production is only about 300 pounds per acre. Forage production estimated by this equation is an average for the Black Hills; actual production will vary according to habitat type.

Severson and Boldt (1977) reported on the preliminary results of a study to measure overstory/understory production in sapling and pole-sized stands of Black Hills ponderosa pine, that had been thinned to GSL's 0, 20, 60, and 100, in 1963 and again in 1973. Their preliminary findings indicated that forage production was greatest under stands where GSL was reduced to 0 or 20. The combined production of wood and forage was greatest at GSL's 60 to 100, but no estimates of combined production were made at higher GSL's. This study, however, reports the results of only one measurement of changes in understory production in relation to overstory density. Consequently, these data cannot be used to quantify changes in forage production under Black Hills ponderosa pine for the range of GSL's, site indexes, cutting cycles, and rotation ages examined. However, some general conclusions can be drawn from the data provided by Pase (1958) and Severson and Boldt (1977). To increase herbage production to even moderate levels (400-500 pounds per

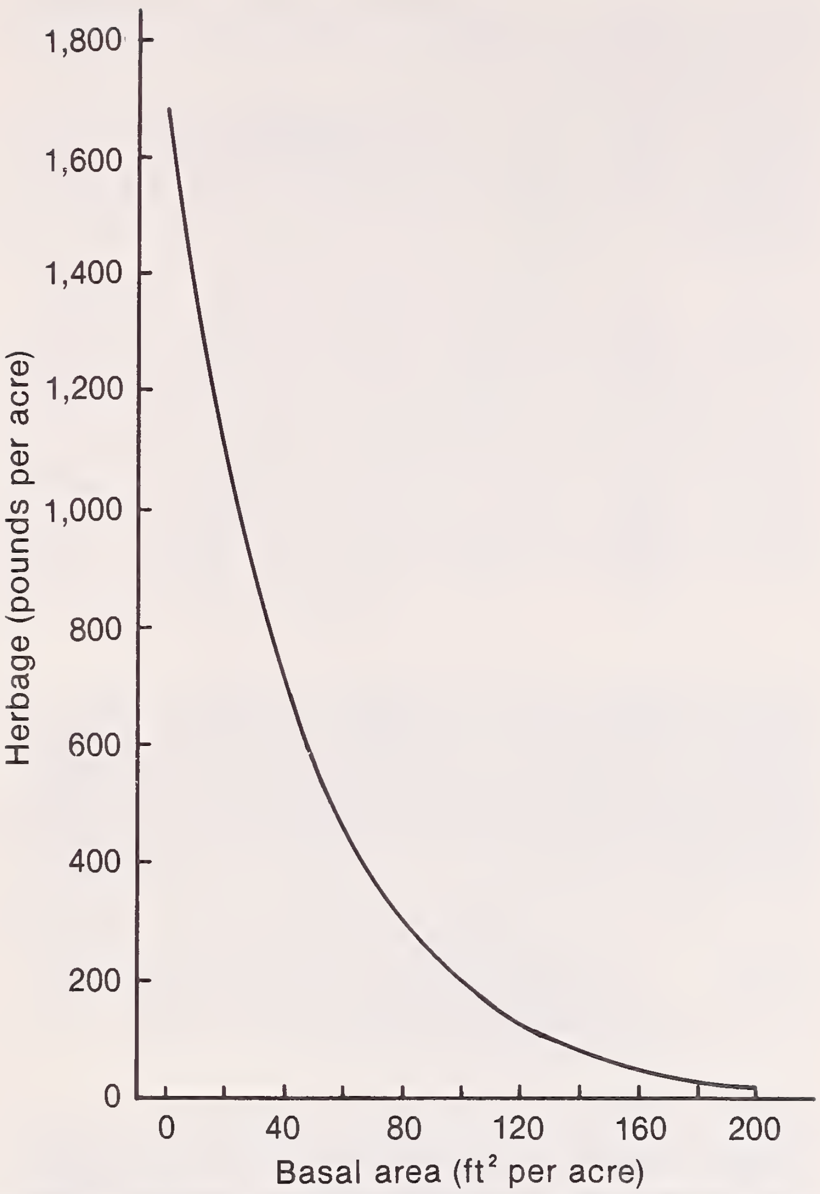

Figure 7.—Relation of herbage production to basal area of Black Hills ponderosa pine (Pase 1958).

acre depending upon habitat type), the manager must be willing to reduce basal area stocking to less than 60 square feet per acre (fig. 8). Moreover, to maintain this forage production, additional cuts must be made in pole-sized or larger stands at intervals of at least every 20 years.

Black Hills ponderosa pine forest areas yield more water than Southwestern or Front Range ponderosa pine forest areas (Gary 1975, Leaf 1975, Orr 1975). They yield less water than the subalpine forest areas in central Rocky Mountains with about the same amount of precipitation, because the distribution pattern is different and evapotranspiration demands of vegetation are higher during a longer and warmer growing season. About 25% of the precipitation is available for streamflow in the Black Hills. In the northern Black Hills, where precipitation is heaviest (average 28 inches), water yields from untreated pine forests, on the Sturgis watersheds, averaged about 7 inches from 1964 to 1969 (Orr and VanderHeide 1973). More than 90% of the annual runoff was produced by 52% of the annual precipitation, which falls during April to June. Winter snowfall is important to the recharge of soil moisture and to early runoff during the spring melt period, but it contributes little to total streamflow. Anderson (1980) reported average streamflow increases of 1.93 inches for 8 years after a partial cut on 50% of the Sturgis watershed. Increases were greatest during the wet years.

The potential for increasing streamflow in the Black Hills should be greater than the slightly more than 1 inch available from Southwestern and Front Range ponderosa pine. The most effective pattern of timber harvest for increasing water yields is to clearcut some portion of first order basins and interbasin areas in small irregular patches, provided that conveyance and other losses would be minimal (Leaf 1975, Orr 1975).

The increase in streamflow resulting from clearcutting is largely caused by reduced evapotranspiration. Redistribution of snow is less important in the Black Hills than in central Rocky Mountain subalpine forests (Leaf 1975). Not only is evapotranspiration reduced by removing trees in cleared patches, but soil moisture is fully recharged earlier in the growing season, resulting in more runoff and a longer runoff period than in uncut or partially cut stands (Orr 1968, 1975). The increase in water available for streamflow diminishes as understory vegetation becomes established. However, it will not return to pretreatment levels until the site is fully occupied by a new stand of trees.

Thinning second growth ponderosa pine also reduces soil moisture deficits, resulting in a greater potential for increased streamflow. But reducing basal area to 80 square feet, a common practice in the Black Hills, will result in less water available for streamflow than at stocking levels less than 60 square feet basal area per acre.

Based on information available from research, observation, and experience, stand density must be reduced and maintained at low stocking levels (less than 60 square feet basal area per acre) to substantially benefit forage and water resources. Foreground landscape esthetics and developed recreational opportunities are generally improved only at moderate den-

Figure 8.—Second-growth Black Hills ponderosa pine on an average site thinned to GSL 40. Stand now averages 7 inches d.b.h., was first thinned in 1963, and was rethinned in 1973.

sities (GSL 60 to 100). However, considerable timber volume is given up at low growing stock levels on the better sites. For example, on site index 70 lands, at GSL 80, with a 120-year rotation and a 30-year thinning schedule, 3,600 fewer fbm per acre will be produced than with GSL 140. If GSL is reduced to 40, the loss in volume production is 10,080 fbm per acre (table 4).

Mountain pine beetles (*Dendroctonus ponderosae* Hopkins) have devastated unmanaged ponderosa pine, particularly the dense second-growth, essentially even-aged stands, in the northern Black Hills. Severe tree-killing has been associated with stand densities ranging from 150 to 260 square feet basal area per acre, and mean tree diameters of about 11 inches d.b.h. (Sartwell and Stevens 1975). The relationship between mountain pine beetle populations, individual ponderosa pine susceptibility, and stand density have not been determined where density has been controlled for the life of the stand. However, it is not unreasonable to believe that managed stands maintained at GSL's 100 to 140, which are below the densities of unmanaged stands most often attacked, will not be as susceptible to beetles.

Middleground and background landscape esthetics require combinations of openings, high and low stocking levels, and uncut timber to provide the variety and contrast that is visually pleasing. The habitats of most wildlife species are affected by changes in vertical and horizontal stand structures resulting from timber harvest. Some wildlife species require openings or the combination of openings and high forests, others require open-standing trees, while the habitat of some wildlife species is devastated by any kind of cutting. But until the habitat requirements of specific wildlife species are better known, the benefits and losses to wildlife associated with the stand parameters examined here cannot be determined.

Management Caution

This simulation program estimates growth responses to different stand parameters that appear reasonable and consistent within limits of present knowledge, but no Black Hills ponderosa pine stand has been under the kind of management envisioned here for long periods of time, and simulation extends beyond the limits of the available data base. Comparisons of estimates with actual values from plots established to provide growth information will be needed to verify simulated responses.

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Appendix

Table A-1.—Basal areas (square feet per acre) after thinning in relation to average stand diameter (inches d.b.h.) and growing stock level

Ave. stand d.b.h. after cutting	Growing stock level										
	40	50	60	70	80	90	100	110	120	140	160
2.0	6.0	7.5	9.1	10.6	12.1	13.6	15.1	16.7	18.2	21.2	24.2
3.0	11.8	14.8	17.7	20.6	23.6	26.6	29.5	32.4	35.4	41.5	47.4
4.0	17.6	22.0	26.4	30.8	35.2	39.6	44.0	48.4	52.8	61.6	70.4
5.0	23.4	29.2	35.0	40.9	46.7	52.5	58.4	64.2	70.0	81.9	93.6
6.0	28.3	35.4	42.4	49.5	56.6	63.7	70.8	77.8	84.9	99.0	113.2
7.0	32.7	40.9	49.1	57.3	65.5	73.7	81.9	90.1	98.2	114.4	130.8
8.0	36.2	45.3	54.4	63.4	72.5	81.6	90.6	99.7	108.8	126.9	145.0
9.0	38.8	48.4	58.1	67.8	77.5	87.2	96.9	106.6	116.2	135.6	155.0
10.0 +	40.0	50.0	60.0	70.0	80.0	90.0	100.0	110.0	120.0	140.0	160.0

Table A-2.—Number of trees per acre after thinning in relation to average diameter (inches d.b.h.) and growing stock level

Ave. stand d.b.h. after thinning	Growing stock level										
	40	50	60	70	80	90	100	110	120	140	160
2.0	277	345	418	488	553	626	692	767	836	968	1,107
3.0	241	301	360	420	481	542	601	660	721	843	964
4.0	202	252	302	353	403	454	504	554	605	707	808
5.0	172	214	257	300	342	385	428	471	513	601	687
6.0	144	180	216	252	288	324	361	396	432	505	577
7.0	122	153	184	214	245	276	306	337	367	428	489
8.0	104	130	156	182	208	234	260	286	312	364	415
9.0	88	110	132	154	175	197	219	241	263	307	351
10.0	73	92	110	128	147	165	183	202	220	257	293

Table A-3.—Average distance (feet) between residual trees in relation to average diameter (inches d.b.h.) and growing stock level

Ave. stand d.b.h. after thinning	Growing stock level										
	40	50	60	70	80	90	100	110	120	140	160
2.0	12.5	11.1	10.2	9.4	8.8	8.3	7.8	7.5	7.2	6.7	6.3
3.0	13.4	12.0	11.0	10.2	9.5	9.0	8.5	8.1	7.8	7.2	6.7
4.0	14.7	13.2	12.0	11.1	10.4	9.8	9.3	8.9	8.5	7.9	7.3
5.0	15.9	14.4	13.0	12.0	11.3	10.6	10.1	9.6	9.2	8.5	8.0
6.0	17.4	15.6	14.4	13.2	12.3	11.6	11.0	10.5	10.0	9.3	8.7
7.0	18.9	16.9	15.4	14.3	13.3	12.6	11.9	11.4	10.9	10.1	9.4
8.0	20.5	18.3	16.7	15.5	14.5	13.6	13.0	12.3	11.8	10.9	10.2
9.0	22.3	20.1	18.2	16.8	15.8	14.9	14.1	13.4	12.9	11.9	11.1
10.0	24.4	21.8	20.1	18.4	17.2	16.2	15.4	14.7	14.1	13.0	12.2

Agriculture—CSU, Fort Collins

Alexander, Robert R., and Carleton B. Edminster. 1981. Management of ponderosa pine in even-aged stands in the Black Hills. USDA Forest Service Research Paper RM-228, 10p. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colo.

Potential production of ponderosa pine in the Black Hills is simulated for various combinations of stand density, site index, age, and thinning schedule. Such estimates are needed to project future development of stands managed in different ways for various uses.

Keywords: Stand growth, stand yield, forest management, *Pinus ponderosa*, Black Hills

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U.S. Department of Agriculture
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